THERMAL AND MECHANICAL PROPERTIES OF RECYCLED POLY(LACTIC ACID)

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Introduction

Biodegradable polymers have experienced increased attention in recent years because of their wide range of applications in biomedical, packaging and agriculture fields. PLA, poly(lactic acid), is a linear aliphatic biodegradable thermoplastic polyester, with good mechanical properties, thermal stability, processability and low environmental impact, widely used as an alternative to conventional polymers. PLA products can be recycled after use either by remelting and reprocessing the material, or by hydrolysis to basic lactic acid [1]. The object of this communication is the study of the possible variation in physical properties induced by subsequent reprocessing cycles of PLA.

Materials and methods

PLA pellets suitable for extrusion (Ingeo TM 2003D, ρ = 1240 kg m^{-3}, MFI = 6 g/10 min) were supplied by NatureWorks LLC, with 4.3 wt% D-isomer content. The polymer underwent five recycling processes, using a single screw extruder, working at 50 rpm with a temperature gradient of 190/200/200/190°C from feed to die zones. Prior to each recycling process, samples were dried at 90°C during 2 hours in a vacuum oven. Compression moulded films (300 µm thick), suitable for nanoindentation measurements, were obtained from original and recycled PLAs.

Thermal, surface mechanical and rheological properties of recycled materials have been compared with those of original PLA.

Results and discussion

Viscosity average molecular weight shows a decrease of 18 % between original PLA and the five times mechanically recycled material. Similarly, the melt flow index (MFI) of the latter material presents a 96 % increase with respect to the original polymer. In addition, the analysis of the rheological curves reveals lower apparent viscosity values for the same shear rate for the recycled samples, being the difference however only significant from the fourth cycle. All these results constitute a clear indication of a degradation process occurring after a few reprocessing cycles, most probably due to chain breaking.

DSC data show that the number of cycles (Fig. 1, left) does not change the glass transition temperature T_g, whereas it induces a lowering of the cold crystallization temperature T_c and a slight decrease of the first appearing melting point T_{m1}. Again these results can be explained by the presence of shorter PLA chains due to chain scission [2].

Depth sensing indentation performed at a constant strain rate by means of an Agilent G200 nanoindenter surprisingly shows that both, indentation modulus *E* and hardness *H*, do not present any variation as a function of the number of processing cycles (Fig. 1, right). It means that *E* and *H* do not depend on changes in molecular weight of the investigated amorphous films. The amorphous nanostructure persists throughout all the recycling processes as revealed by wide angle x-ray scattering (WAXS). In order to detect any mechanical difference arising from the structural changes provoked on recycling PLA, it was decided to study a visco-elastic-plastic property such as creep. For this purpose, hardness data for different PLA films have been investigated as a function of various strain rates and the creep exponents have been evaluated and discussed.

Finally, cold crystallized PLA films at fixed temperatures also reflect a different surface mechanical behaviour among original and recycled PLAs, mainly due this time to the diverse degree of crystallinity achieved.

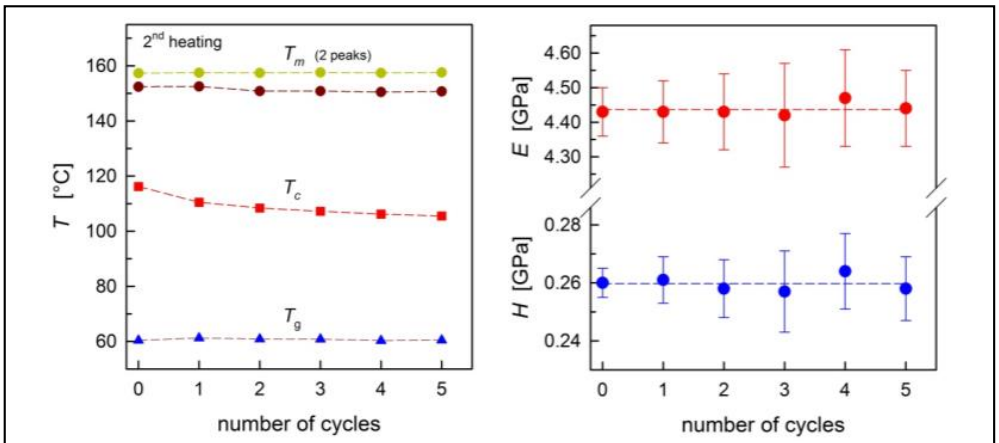

Figure 1. DSC data obtained during the second heating at 5°C/min (left) and depth sensing indentation mechanical properties (right) as a function of number of recycling processes.

References

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Acknowledgements

The authors wish to thank the financial support of MICINN, Spain, under grant FIS2010-18069 and ECOEMBALAJES ESPAÑA S.A. (ECOEMBES).